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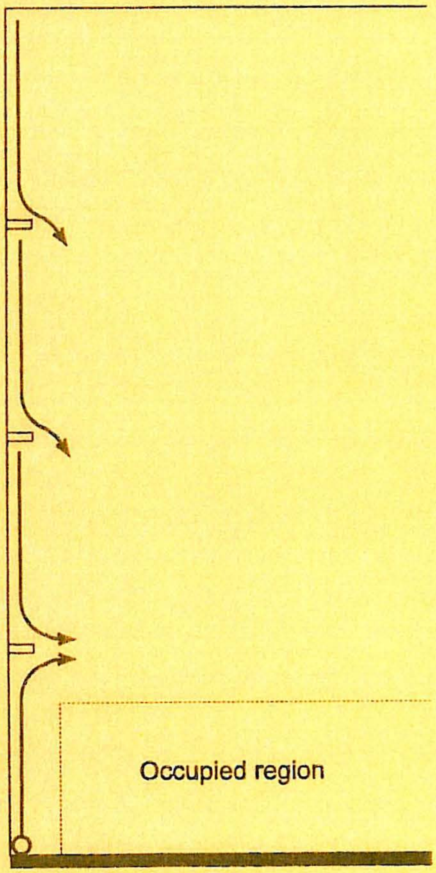

INDOOR ENVIRONMENTAL TECHNOLOGY
PAPER NO. 58

Presented at ROOMVENT '96, Fifth International Conference on Air Distribution in Rooms, Yokohama, Japan, July 17-19, 1996

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Obstacles, an Energy-Efficient Method to Reduce Downdraught from Large Glazed Surfaces

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ABSTRACT

Thermal discomfort due to downdraught from glazed surfaces are often met by convectors placed close to the surface, but this may lead to increased energy consumption.

The objective of this research is to investigate the effect of a horizontal obstacle on the boundary layer flow at a high cold vertical surface.

Full-scale experiments show that the velocities in the boundary layer flow below the obstacle are reduced with increased obstacle width. At a critical width the boundary layer flow above the obstacle does not affect the velocity level below the obstacle. Therefore, when calculating the velocity in the boundary layer flow at the bottom of the surface, the effective height of the surface will only be from the last obstacle to the floor.

In the near-surface region the velocities in the flow along the floor are also reduced with increasing obstacle width. At a distance of more than 1.5-2.0 m from the surface the obstacle has no effect on the velocity level.

KEYWORDS

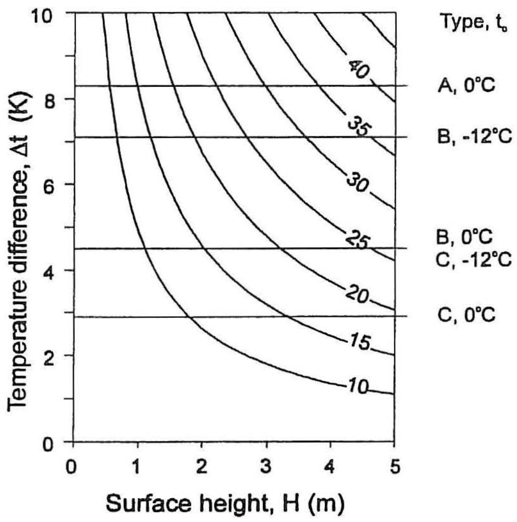
Downdraught, Free convection, Boundary Layer Flows, High Glazed Surfaces

INTRODUCTION

Glazed facades have become more and more popular as an integrated part of the building and its design. Glass extensions and atria are often found in hotels, hospitals, office buildings, houses and shopping malls. They create a naturally lit working and living environment and the energy consumption for heating and electrical lighting is decreased due to the gain of passive solar energy and daylight.

During winter time though, the glazed surfaces may cause thermal discomfort from cold radiation and downdraught due to the low surface temperature. Heiselberg (1994); has investigated the relationship between temperature difference, Δt, surface height, H, and the maximum percentage of dissatisfied, PD, due to downdraught (Figure 1). It appears that appropriate choice of pane can solve the problem passively for surfaces that are not higher than normal room height, but for larger surfaces the boundary layer flow is still the cause of thermal discomfort.

Traditionally the problem is solved either by increasing the surface temperature by convectors placed close to the surface in different heights above the



Type A Double glazed window, U=3.0 W/m²K
Type B Double glazed window with one layer of low emission glass and argon filling, U=1.6 W/m²K
Type C Triple glazed window with two layers of low emission glass and argon filling, U=1.0 W/m²K

Figure 1 The maximum percentage of dissatisfied, PD, in the occupied zone of a room with a cold vertical wall and a room temperature of 22°C as a function of the temperature difference between the room and the surface, Δt, and of the height of the surface, H.

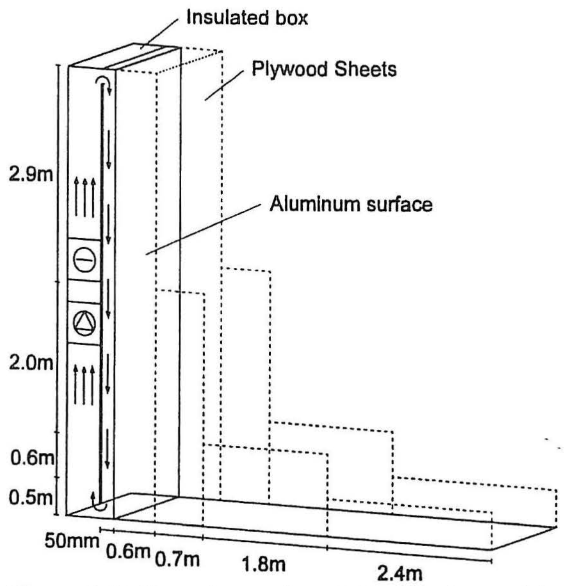


Figure 2 Outline of experimental facility located in a laboratory hall.

floor or by ventilation slits that neutralize the cold air flow and force it into the room above the occupied region. Both solutions however lead to increased energy consumption and are not ideal

Heiselberg et al. (1995); have shown that horizontal obstacles on the cold surface can reduce the risk of thermal discomfort due to downdraught for surfaces of normal room height. Therefore, a series of full-scale experiments has been conducted to investigate the influence of horizontal obstacles on the cold boundary layer flow for a higher surface.

EXPERIMENTAL SETUP

The experiments were carried out in a two-dimensional case at a 6 m high and 2 m wide test surface with a horizontal obstacle located 3 m above the floor. The experimental facility were located in a small laboratory hall, where calm and steady state conditions were maintained. It consisted of two chambers connected with two narrow slits (50mm) at the top and the bottom. Behind the aluminium surface were a narrow chamber (50mm wide) with a two-dimensional air flow flowing from the top to the bottom of the surface cooling the surface to the wanted temperature. In the large chamber a fan circulated air between the two chambers and a cooling coil where cooling the air. It was possible to maintain a very even temperature distribution on the surface. The surface temperature was measured in 19 points. The temperature variation depended on the temperature difference between the surface and the room air and varied less than ±1% of the average temperature difference for Δt = 9°C, and less than that for smaller temperature differences. During experiments the average surface temperature varied less than 0.5°C. The temperature in the laboratory hall was measured in 13 heights from the bottom to the top of the surface and the gradient was at any time during the experiments less than 0.4°C/m and the average temperature variation was less than 0.5°C. Plywood sheets were shielding the flow to ensure two-dimensional flow conditions both at the wall and in the air flow along the floor and to minimize disturbances from any air flows in the laboratory hall. Air flow conditions at different temperature differences between the cold surface and the ambient air, and different widths of the obstacle were examined, see table 1.

Table 1 Matrix of performed measurement. X) velocity profiles in the boundary layer flow, O) velocity profiles in the air flow along the floor.

	Obstacle Width, w (m)				
Δt (K)	0	0.1	0.3	0.4	0.6
1	X,O		X,O		
3	X,O		X,O		
9	X,O	X,O	X,O	X,O	X,O
15	X,O		X,O		

The temperatures were measured with thermocouples. Air velocities were measured with hot-sphere anemometers together with a data processing device calibrated to an accuracy of ±0.025 m/s in the range of 0.05m/s and 1.0m/s. The anemometers were calibrated both in a downward (vertical) and in a horizontal air flow.

COLD DOWNDRAUGHT

Cold downdraught is caused by a free convective boundary layer flow, which is created due to the temperature difference between the cold surface and the ambient air. The maximum velocity in the boundary layer flow is given by:

$$v_{max}(h) = 0.07\sqrt{h\Delta t} \qquad (1)$$

where

$v_{max}(h)$ = maximum velocity in the boundary layer (m/s)

h = distance from the top of the surface (m)

Δt = temperature difference between the cold surface and the ambient air (K)

At the obstacle the boundary layer flow will either separate from or reattach to the surface depending on the width of the obstacle, see Figure 3. This is similar to a wall jet that deflects into the occupied zone at a critical height of a ceiling-mounted obstacle. In case A the width is below the critical size and the boundary layer flow reattaches to the surface below the obstacle but the velocity level is reduced. Right below the obstacle a recirculation zone is established. In case B the width is above the critical size and the boundary layer flow separates from the surface and flows into the occupied zone. Below the obstacle a new boundary layer flow is established.

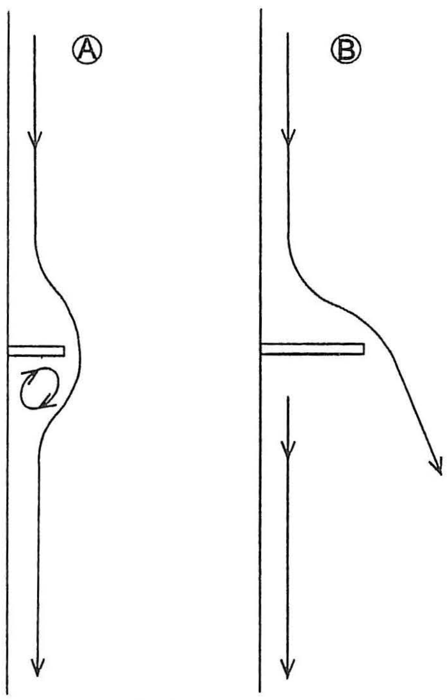


Figure 3 Principle of flow conditions at a cold vertical surface with an obstacle of a size A) below and B) above the critical width.

Flow along the Surface

In order to compare experiments carried out at different temperature differences the measured maximum velocity is normalized with the calculated maximum velocity at the foot of the surface according to Equation 1.

$$v^* = \frac{v(h)}{v_{max}(H)} \qquad (2)$$

where

v^* = non-dimensional maximum velocity (-)

$v(h)$ = measured maximum velocity in the boundary layer (m/s)

$v_{max}(H)$ = maximum velocity in the boundary layer according to Equation 1

H = height of the surface (m)

The measured non-dimensional maximum velocities in the boundary layer along the surface are shown in Figure 4 for different widths of the obstacle together with the expected values for a boundary layer flow at a plane surface starting respectively 3 m and 6 m above the floor.

At an obstacle width of w=0.1m the boundary layer flow reattaches quickly to the surface and thus the velocity level in the boundary layer flow below the obstacle is higher than for a plane surface with H=3 m. The obstacle however does reduce the velocity in the boundary layer flow considerably compared to a plane surface with H=6 m. If the obstacle width is increased to w=0.3 m, the velocity level of the boundary layer flow will decrease significantly due to entrainment of room air before it reattaches to the surface and the velocity level will be lower than in the new boundary layer flow below the obstacle. Then, an additional increment in the obstacle width will not reduce the velocities any further. Consequently, the desired effect, that the flow above the obstacle does not increase the velocity level in the flow below the obstacle, can be obtained even if the boundary layer flow does not separate from the surface.

Figure 5 shows the "critical" width as a function of the temperature difference between the surface and the room air in the two cases. In the first case the critical width is found by smoke tests as the smallest width at which the flow separates from the surface. In the second case the critical width is found by velocity

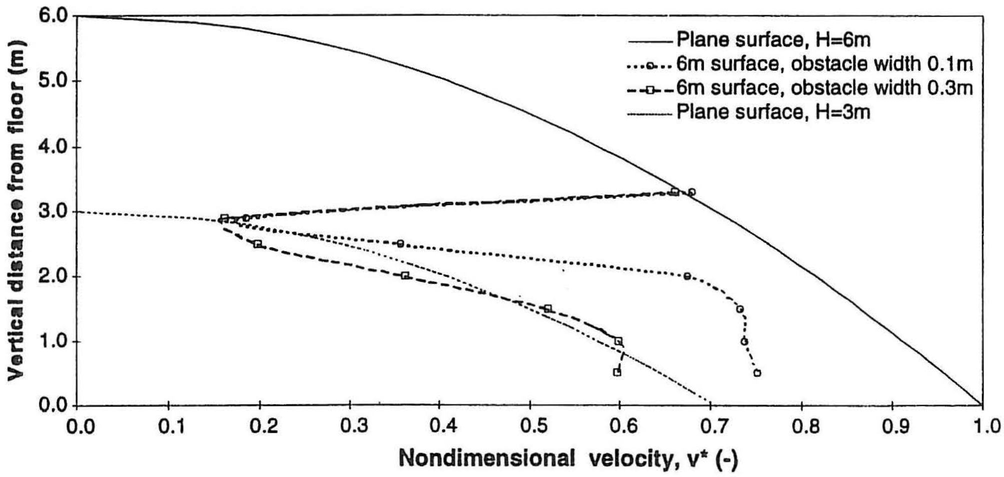


Figure 4 Non-domensional maximum velocity in the boundary layer flow in different heights above the floor and for a temperature difference, Δt=9K. The values are measured at 6 m high surfaces with obstacles of different widths and calculated for plane surfaces of heights of 3 m and 6 m, respectively.

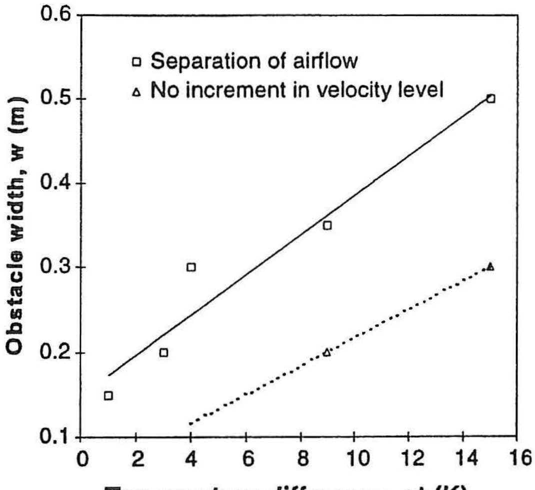


Figure 5 Critical width of the obstacle, w, as a function of the temperature difference, Δt. The critical width is given both as the smallest width at which the flow seperates and as the smallest width at which the velocity level is not increased.

measurements as the smallest width at which the velocity level in the boundary layer flow under the obstacle is not increased by the reattachment of the flow from above the obstacle. For a temperature difference of Δt=9K it appears that the boundary layer flow separates from the surface at w=0.35 m while the velo-city level in the boundary layer flow below the obstacle is no longer increased at w=0.2 m.

Flow in the Occupied Region

The velocities in the boundary layer flow along the surface are not interesting from the point of view of thermal comfort because they always occur in the near surface region outside the occupied zone. Therefore, the maximum velocities in the air flow in the occupied region have to be examined to evaluate the thermal comfort. The maximum velocity in the air flow in the occupied region for boundary layer flow from a plane surface is used as reference and given by Heiselberg (1994);

$$u_{max}(x) = \begin{cases} 0.055\sqrt{H\Delta t} & x \leq 0.4\,m \\ 0.095\dfrac{\sqrt{H\Delta t}}{x+1.32} & 0.4 < x < 2.0\,m \\ 0.028\sqrt{H\Delta t} & x \geq 2.0\,m \end{cases} \quad (3)$$

where

$u_{max}(x)$ = maximum velocity in the occupied region (m/s)

x = distance from the surface (m)

It can be seen from Equation 3 that the maximum velocity in the occupied region has decreased more than 20% compared to the maximum velocity in the boundary layer. This is due to the air flow conditions in the corner between the surface and the floor where the flow undergoes a change in direction from vertical to horizontal.

The linear relation between the maximum velocity in the occupied region, u_{max}, and $\sqrt{H\Delta t}$, expressed by the velocity coefficient k, which is found for a plane surface, is also found for a surface with an obstacle. Figure 6 shows the relation between the velocity coefficient, k, and

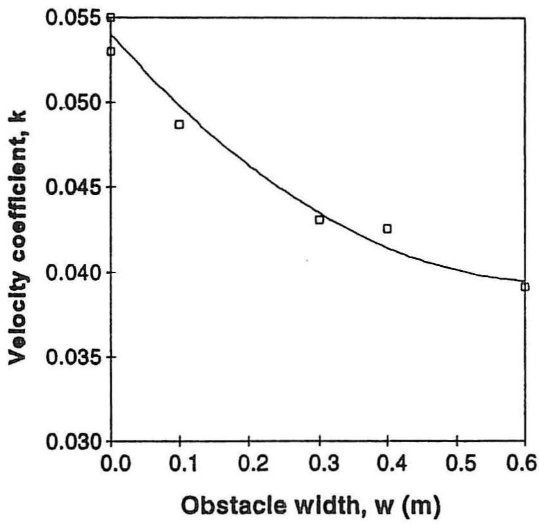


Figure 6 The velocity coefficient, k, as a function of the obstacle width for a 6 m high vertical surface with an obstacle positioned 3m above the floor. The temperature difference between the surface and the room air were 9°C.

the width of the obstacle, w. The velocity coefficient and thereby the maximum velocity in the air flow in the occupied zone decreased at increasing width of the obstacle. For an obstacle width of w=0.3 m the maximum velocity was reduced with 15% compared to a plane surface. The constant is reduced to k=0.040 for a surface with an obstacle width of 0.6m. The velocity level in the occupied zone found by Equation 3 and a constant of 0.040 corresponds to the velocity level from 3m high surface. Therefore an increase in obstacle width will not give a further decrease in the velocity level in the occupied zone.

Figure 7 shows the measured local maximum velocities in the flow in the occupied zone found for different widths of the obstacle at the vertical surface as a function of the distance from the surface. The velocities are normalized with the maximum velocity close to the surface calculated from Equation 3 for a surface with H=6 m. The expected non-dimensional maximum velocities for plane surfaces with heights of H=3m and H=6 m, respectively, are also shown

In the near surface region the velocities in the flow in the occupied zone are reduced with increasing obstacle width due to the reduced velocity level in the boundary layer flow. For a large obstacle the velocity close to the surface is approximately the same as for a plane surface of half the height. At a distance of more than 1.5-2.0 m from the surface the obstacle has no effect on the velocity level. Though the obstacle only affects the velocity level locally the risk of thermal discomfort is decreased due to the reduced maximum velocity in the occupied zone.

DISCUSSION

An obstacle will only be efficient if the boundary layer flow is turbulent. To fulfill this also for smaller temperature differences the distance between two successive obstacles should not be less than 2 m (Heiselberg et al. 1995).

Although the velocities in the occupied zone are reduced, the boundary layer flow may still under certain conditions be the cause of thermal discomfort. Consequently, it will be necessary to combine the use of obstacles with a traditional solution, e.g. a convector, to solve the problem with cold downdraught. Arran-

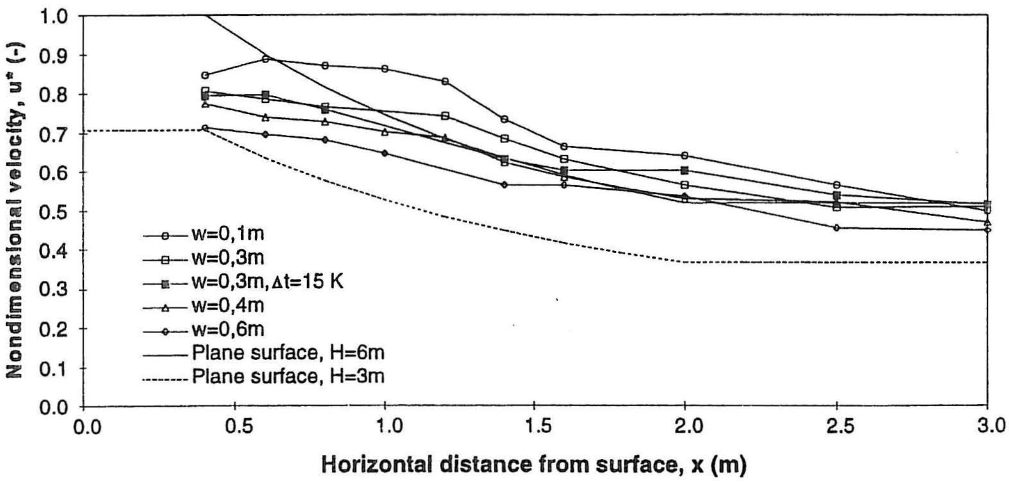


Figure 7 Non-dimensional maximum velocities in the air flow in the occupied zone as a function of the distance to the vertical surface measured for surfaces with obstacles of different width and calculated for plane surfaces of the heights H=3m and H=6m, respectively. The temperature difference between the surface and the room air was 9°C where nothing else is specified.

gements to prevent discomfort due to cold downdraught are often designed with respect to the momentum flow in the boundary layer at the foot of the surface. From Eckert and Jackson (1951); the following Equation for the momentum flow can be set up

$$I = 2.4 \cdot 10^{-4} \Delta t^{0.9} H^{1.7} \qquad (4)$$

where

I = momentum per unit width at the foot of the surface (N/m)

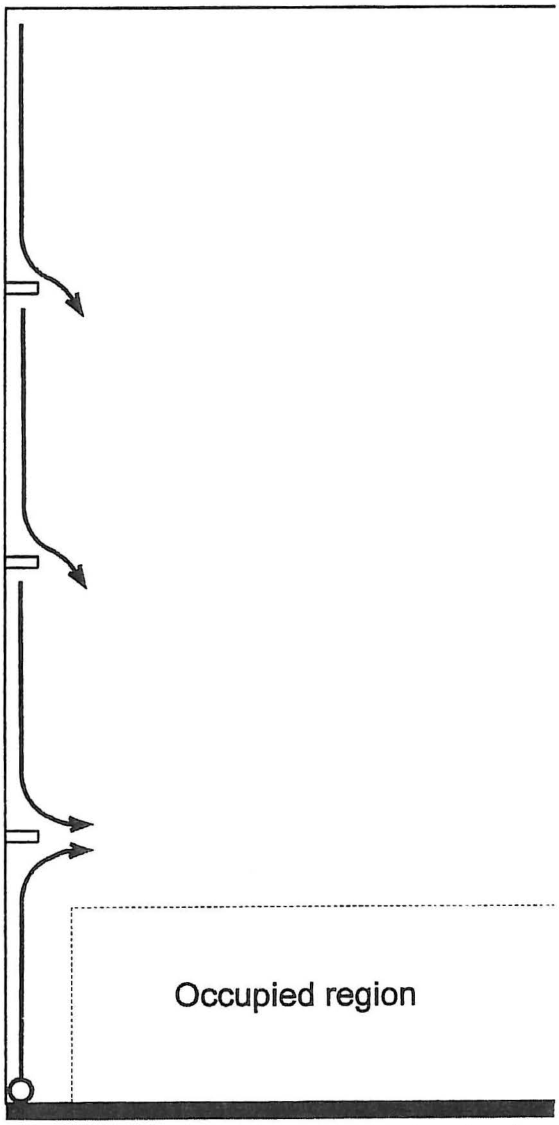


Figure 8 The structural system of a glazed surface can serve as natural obstacles and so partition the surface and it will only be necessary with arrangements in the occupied zone to prevent downdraught.

From Equation 4 it is seen that the momentum strongly depends on the height of the surface and therefore it is beneficial to divide larger surfaces into smaller parts. E.g. if a surface with H=10 m is divided into four parts of 2.5 m the momentum for each of these will be reduced to 10% of the momentum for the entire surface.

Traditionally the surface has been divided into smaller parts by convectors or ventilation slits in different heights above the floor but often the structural system of the glazed surface can serve as natural obstacles and so partition the surface. The discomfort in the occupied region due to cold downdraught can then be prevented by arrangements in the occupied region only, see Figure 8, and both the initial and operating costs will be reduced considerably.

CONCLUSIONS

The experiments have shown that the structural system of the glazed surface can serve as natural obstacles and so partition the surface. The discomfort in the occupied region due to cold downdraught can then be prevented by arrangements in the occupied region only and both the initial and operating costs will be reduced considerably.

At a certain width of the obstacle the boundary layer flow above the obstacle will not affect the velocity level in the flow below the obstacle. Therefore, when calculating the velocity level at the bottom of the surface, the effective height of the surface will only be from the last obstacle to the floor. Also the velocity level in the occupied zone close to the vertical surface (<1.5-2 m) will decrease, while the velocity level further from the surface will remain at the same level as for a plane surface.

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